Cog-TV

Business and Technical Analysis of Cognitive Radio TV Sets for Enhanced Spectrum Access (CNS 1247941/1247914)

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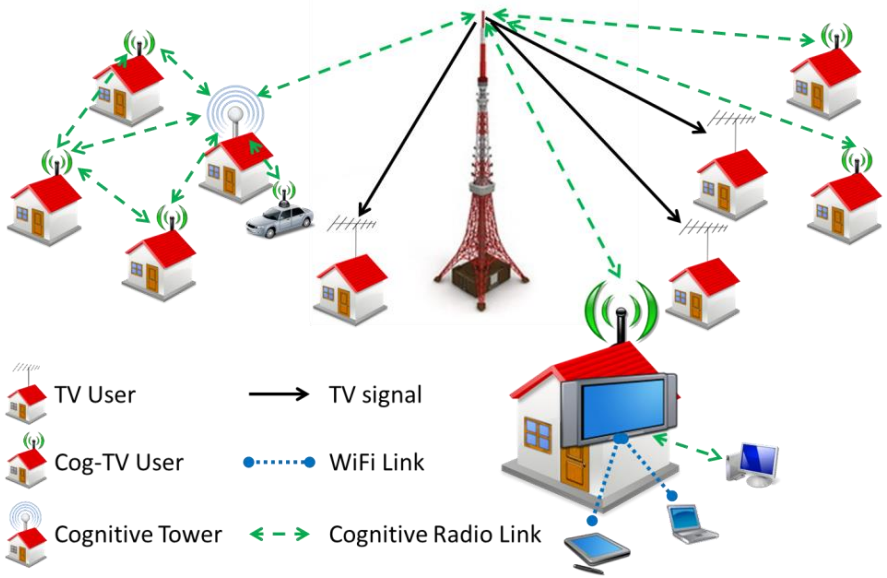


- Existing argument: Emerging cognitive radio networks result in a technical and an economical conflict with the TV broadcast companies
- Our view: Conflict → Opportunity
- Is it economically and technically viable for broadcast companies to utilize TV white spaces for
  - low-cost Internet provision
  - web-enabled TV services?

Research Goals of Cog-TV

Research Goals:

- **Business Aspects of Cog-TV:** Dynamic pricing scheme to balance demand between peak and non-peak periods; infrastructure cost analysis for Cog-TV integrated network.
- **Neighborhood Watch :** Analysis of spectrum sensing accuracy and correlation in the spectrum sensing information; optimal sensing scheduling algorithms to minimize sensing overhead and maximize bandwidth.
- **Cog-TV-initiated Spectrum Handoff:** Methodologies to estimate the opportune times to initiate spectrum handoff; strategies for broadcast companies to address the self-competition challenge that results in serving two types of customers: TV viewers and cognitive Internet users.

Potential Payoffs:

- Enable transformative and economically viable CRN development and management approaches
- Bring affordable Internet service to a large group of American households
- Impact consumer market by creating a niche market in new TV sets

Business Aspects of Cog-TV

- **Dynamic pricing:**
  - The capacity of CRN varies based on factors such as the availability of TV white space, choice of TV channel view, and population density.
  - The TV broadcasting company will post hourly prices in real time based on changing capacity and predicted demand, especially higher prices at periods of peak demand.
  - Changing prices will motivate customers to shift their Internet activity to periods of high capacity but low demand.
  - As a result, customers will minimize their connection cost. TV broadcast companies will maximize their profit and increase customer satisfaction by providing Internet to more customers at even lower prices

- **Cost of Cog-TV integrated network:**
  Cost of building the Cog-TV infrastructure in the urban and rural areas will be analyzed separately to determine economic feasibility.

Cog-TV

- TV spectrum ownership gives TV broadcast companies a major advantage in extending their business to become an Internet service provider using the TV white spaces
- *Cognitive radio-equipped TV sets (**Cog-TVs**):*
  - TV tuner, integrated CR interface, and Wi-Fi interface
- Cog-TV provides three main capabilities
  - Low-cost access to the Internet in residential and commercial spaces
  - Interference measurement of TV services for enhanced quality of user experience
  - Localized collaborative spectrum sensing for fine-grained spectrum management

- **Broader Impacts:** Interdisciplinary research in operations research, decision sciences, wireless communication, networking, and optimization
- **Dynamic Pricing:** Change price dynamically to manage demand
  - Provide real-time pricing information to customers
  - Customers can access Internet strategically to lower their bills
- **Neighborhood Watch:** Utilize network of Cog-TVs to improve unlicensed band utilization through collaborative sensing mechanism

Main Threads of the Project

- **Correlation-based Collaborative Spectrum Sensing:** Provably optimal cooperative algorithms through a novel sensing deficiency virtual queue [1] concept
  - Exploit the four dimensions of correlation (spatial, temporal, spectral)
  - Explore resource cost functions based on price paid by the customer
  - Develop distributed algorithms
- **Cog-TV-Initiated Spectrum Handoff:** Account for TV tune-in events and predictions to enable proactive spectrum handoff decisions
  - TV viewers and cognitive Internet users are both customers
  - Evaluate the costs and benefits of staying on a given channel despite TV tune-in on the channel
  - Self-competition for Cog-TV-initiated spectrum handoff
- **Evaluation Testbed:** Utilizes distinct properties of Nebraska (sparse population) and Ohio (dense population)
- **Education and Outreach:** Attract undergraduate students by UCARE (UNL) and UROP (OSU) programs. Reach underrepresented groups and high schools, e.g., Ohio State Women in Engineering Program, UNL 4-H program.

[1] D. Xue, E. Ekici, M. C. Vuran, ``(CORN)^2: Correlation-based Cooperative Spectrum Sensing in Cognitive Radio Networks,'' *in Proc. **Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt'12)***, Paderborn, Germany, May 2012.

Case Study:

Available Channel Capacity

with

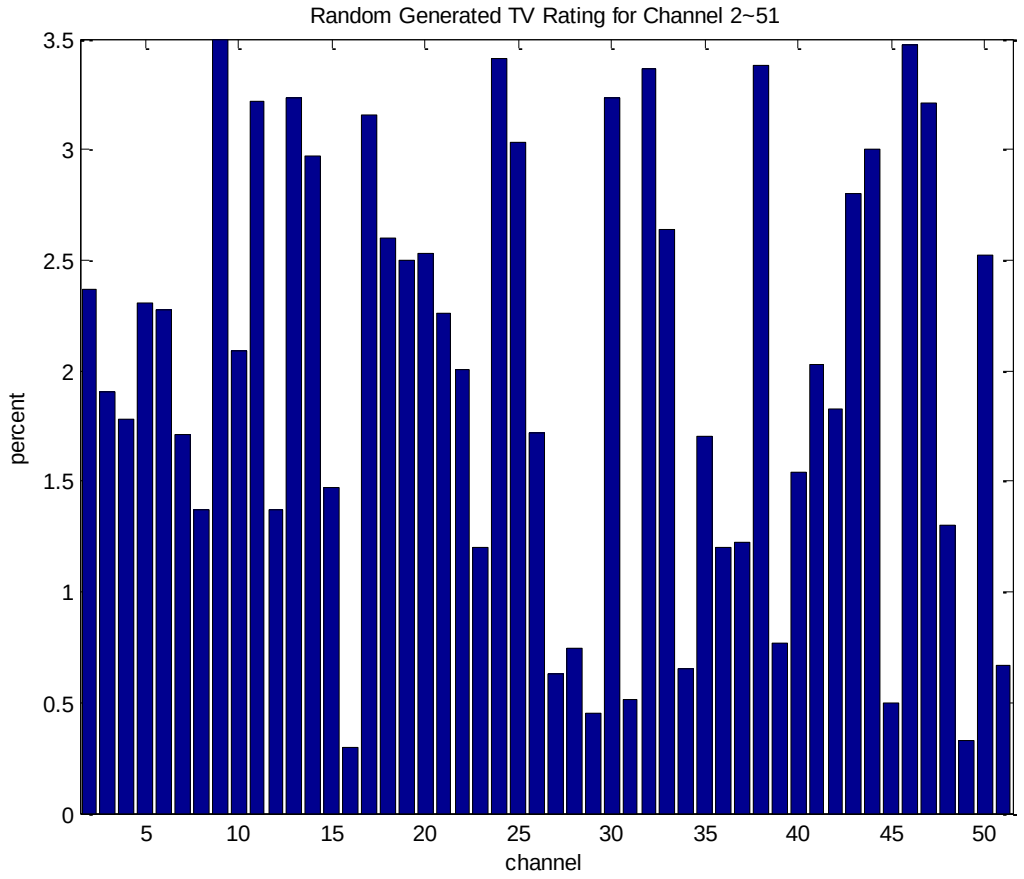
Cog-TV vs. current FCC Rules

Lincoln, NE & New York, NY

or

"Is it really worth it?"

TV Rating Assumption

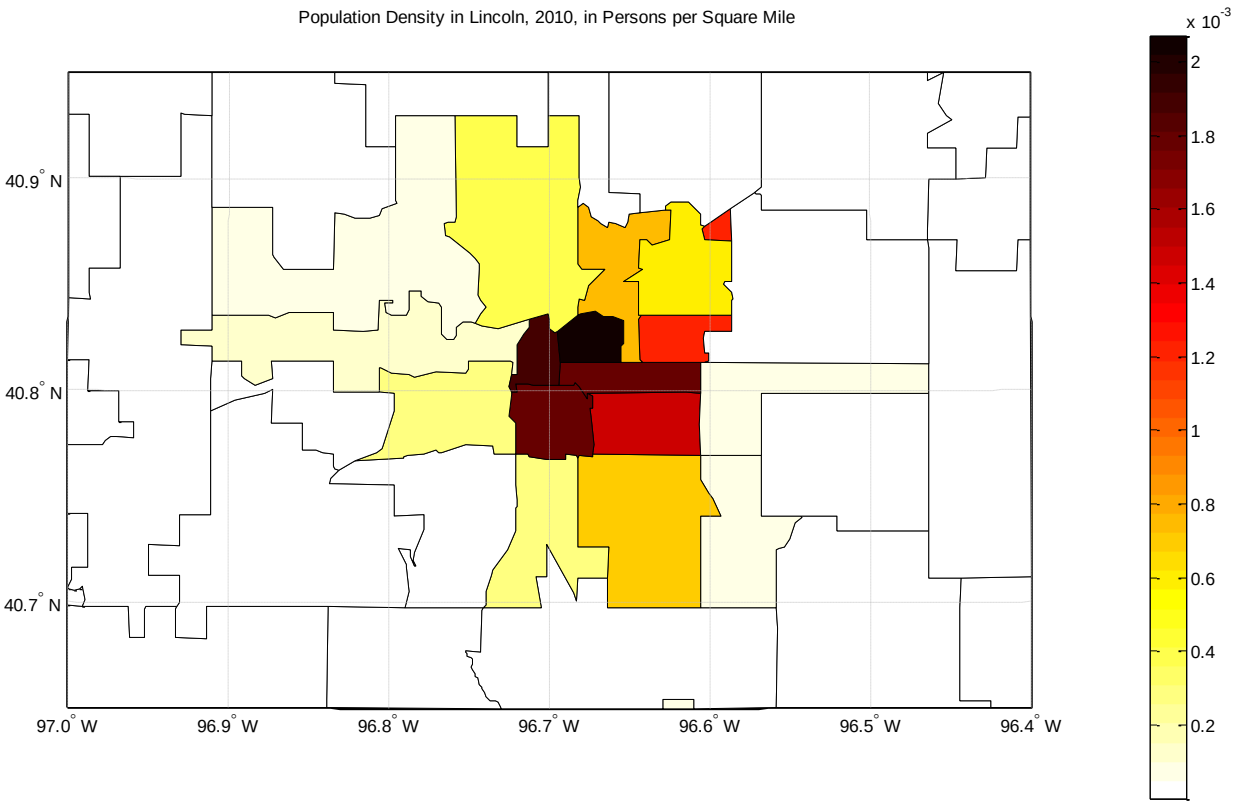


Assumptions:

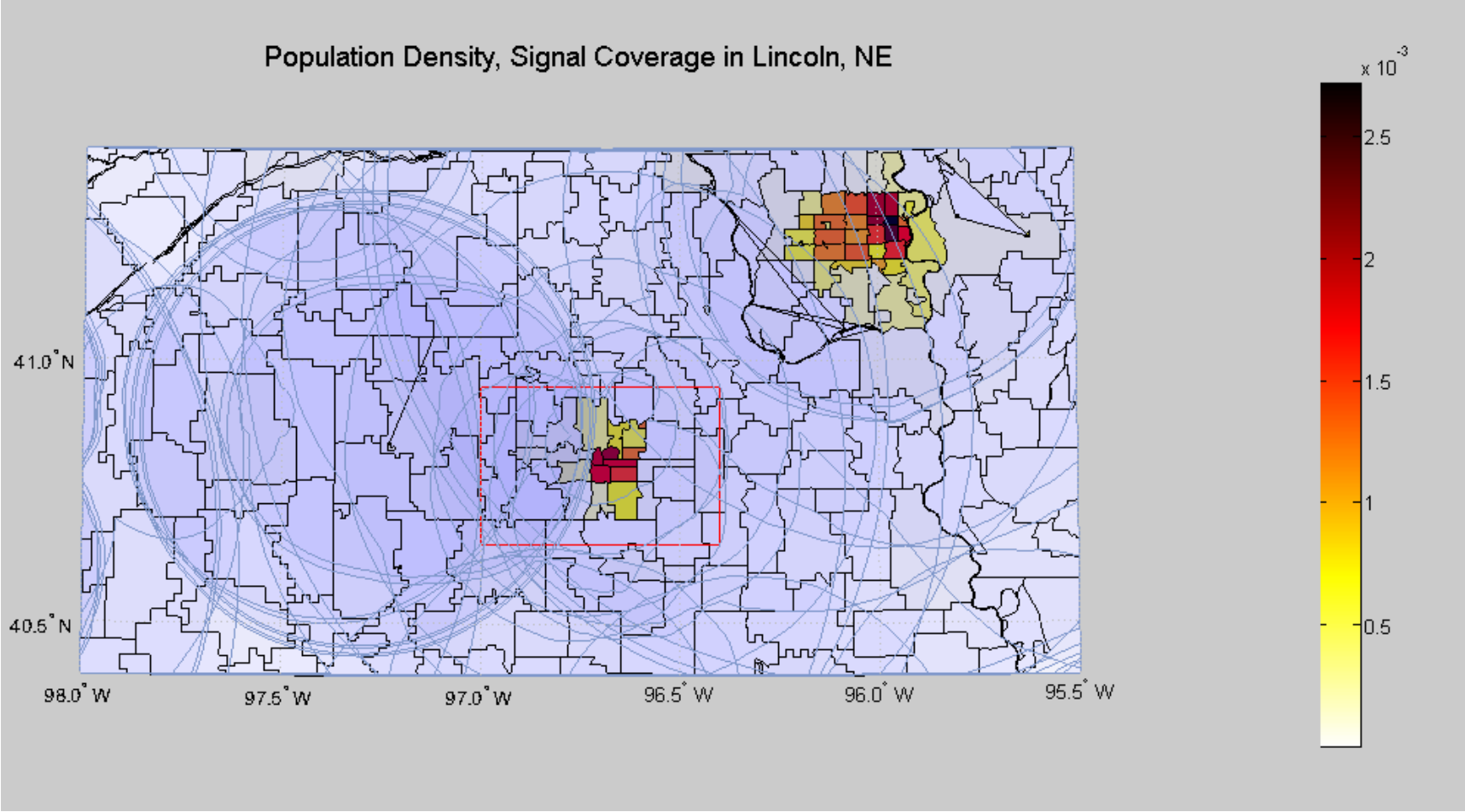
(1) 8% of population are watching TV,

(2) Randomly generated rating data

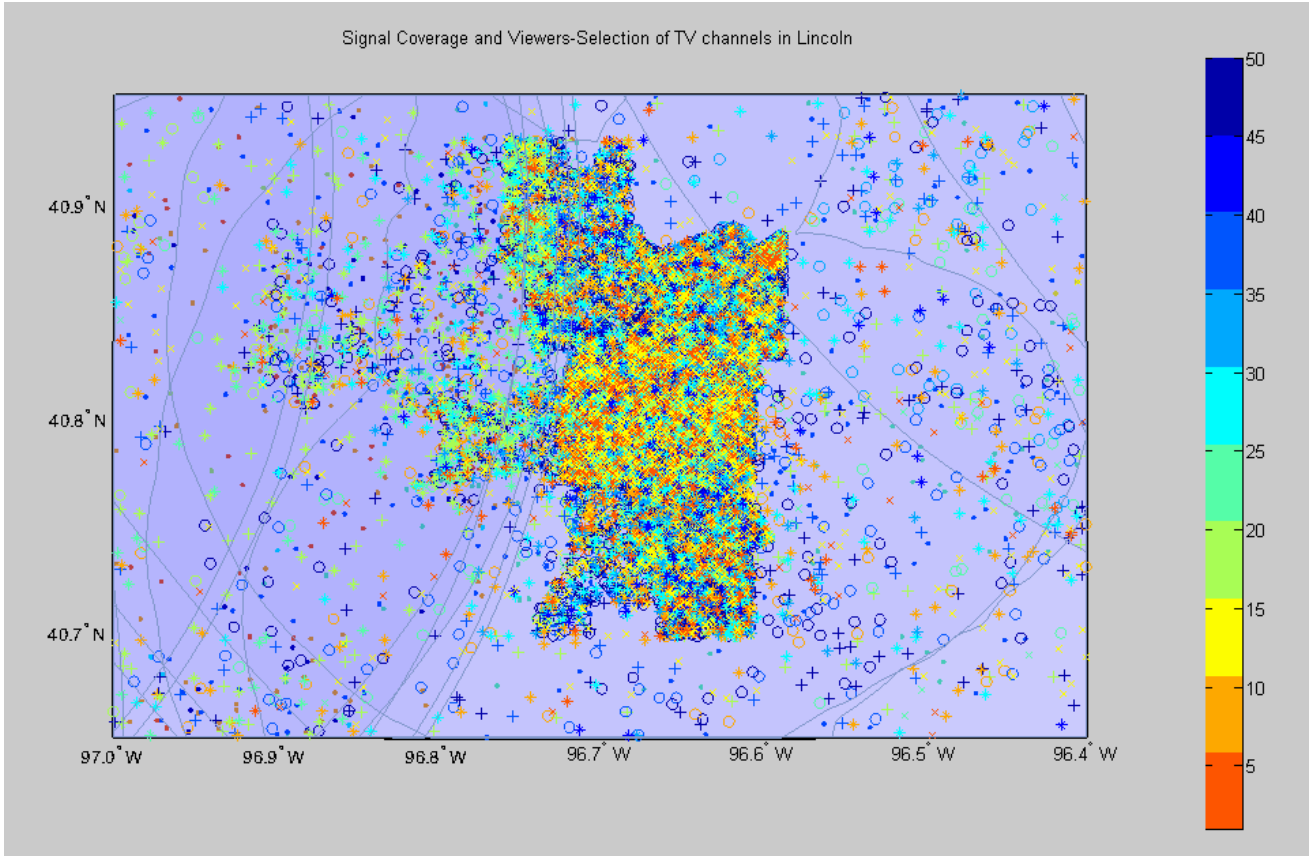
Population Density of Lincoln



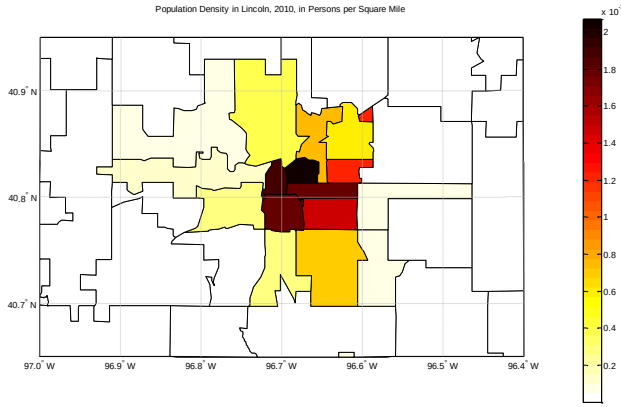
Population and TV Tower Coverage Lincoln, NE

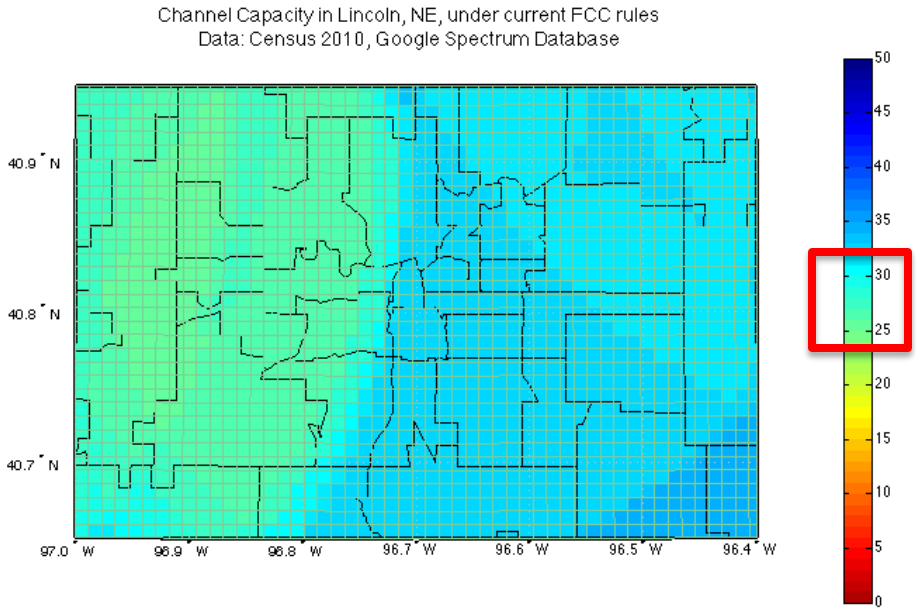


TV Channel Viewership in Lincoln

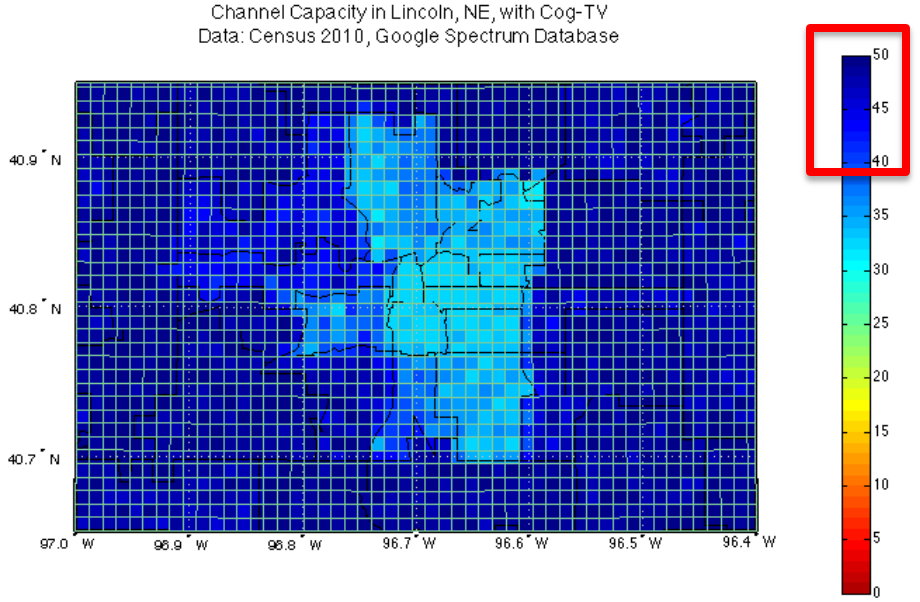


Available TV Channels in Lincoln
FCC vs Cog-TV (1km Cell)



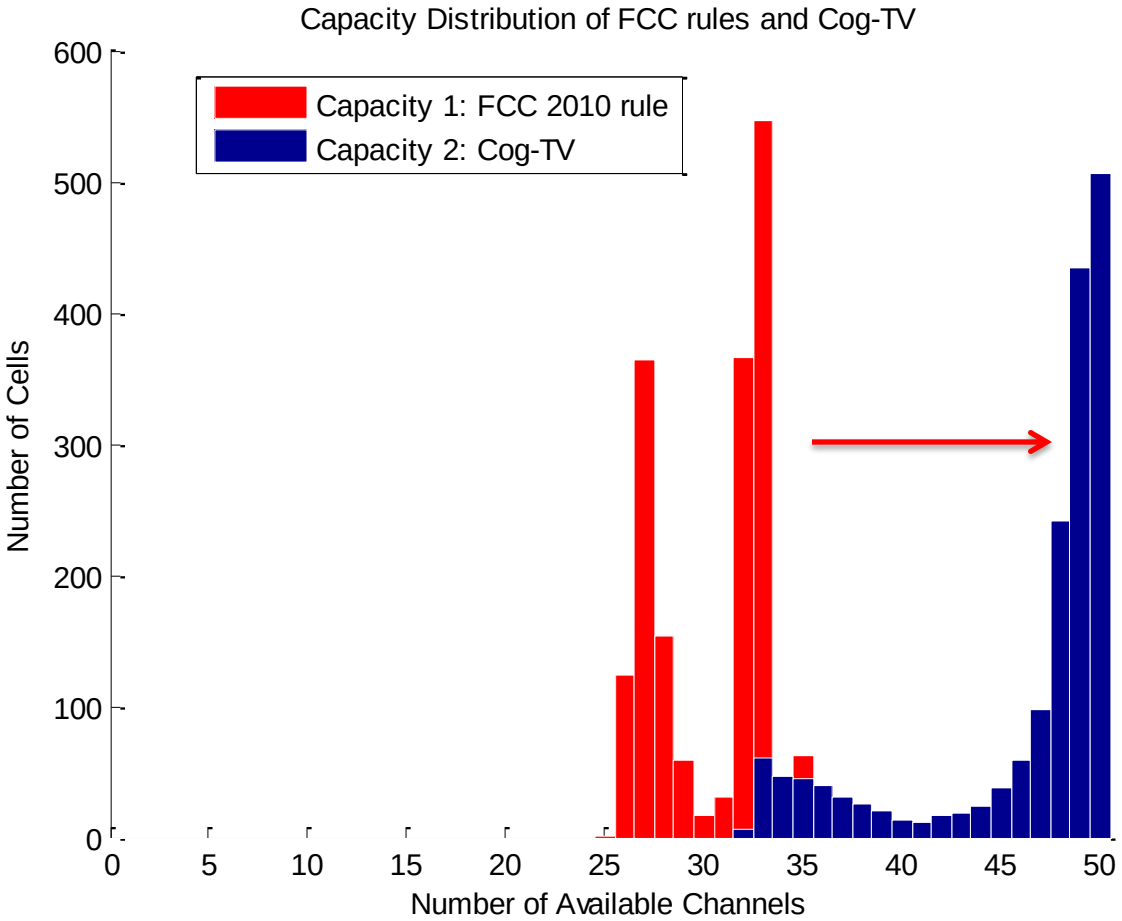


FCC



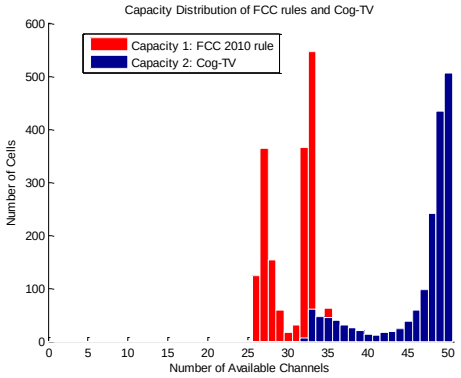
Cog-TV

Available Channels in Lincoln (FCC vs Cog-TV)

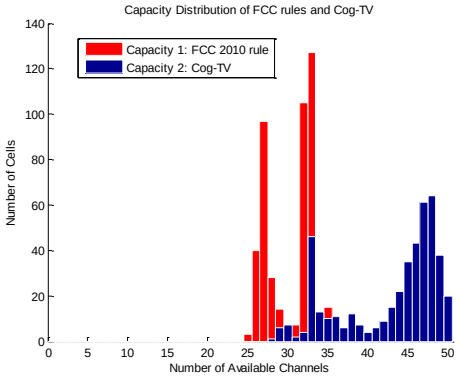


Cell Size: 1 km

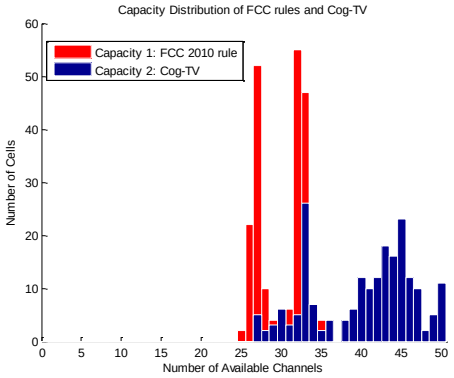
Available Channels in Lincoln (FCC vs Cog-TV)



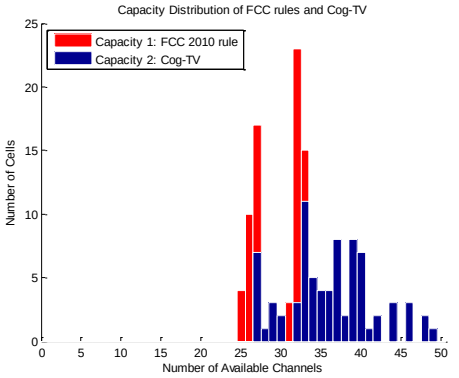
Cell Size: 1 km



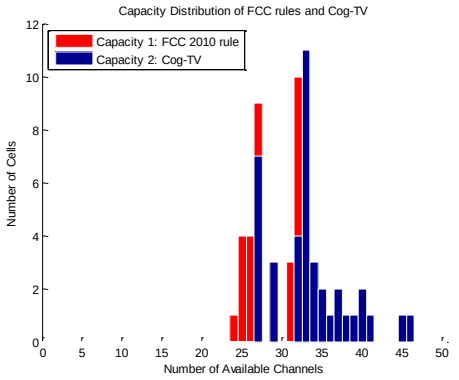
2 km



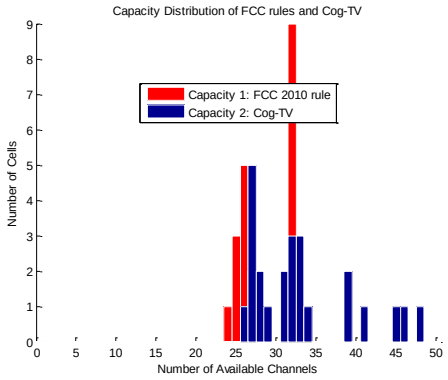
3 km



5 km

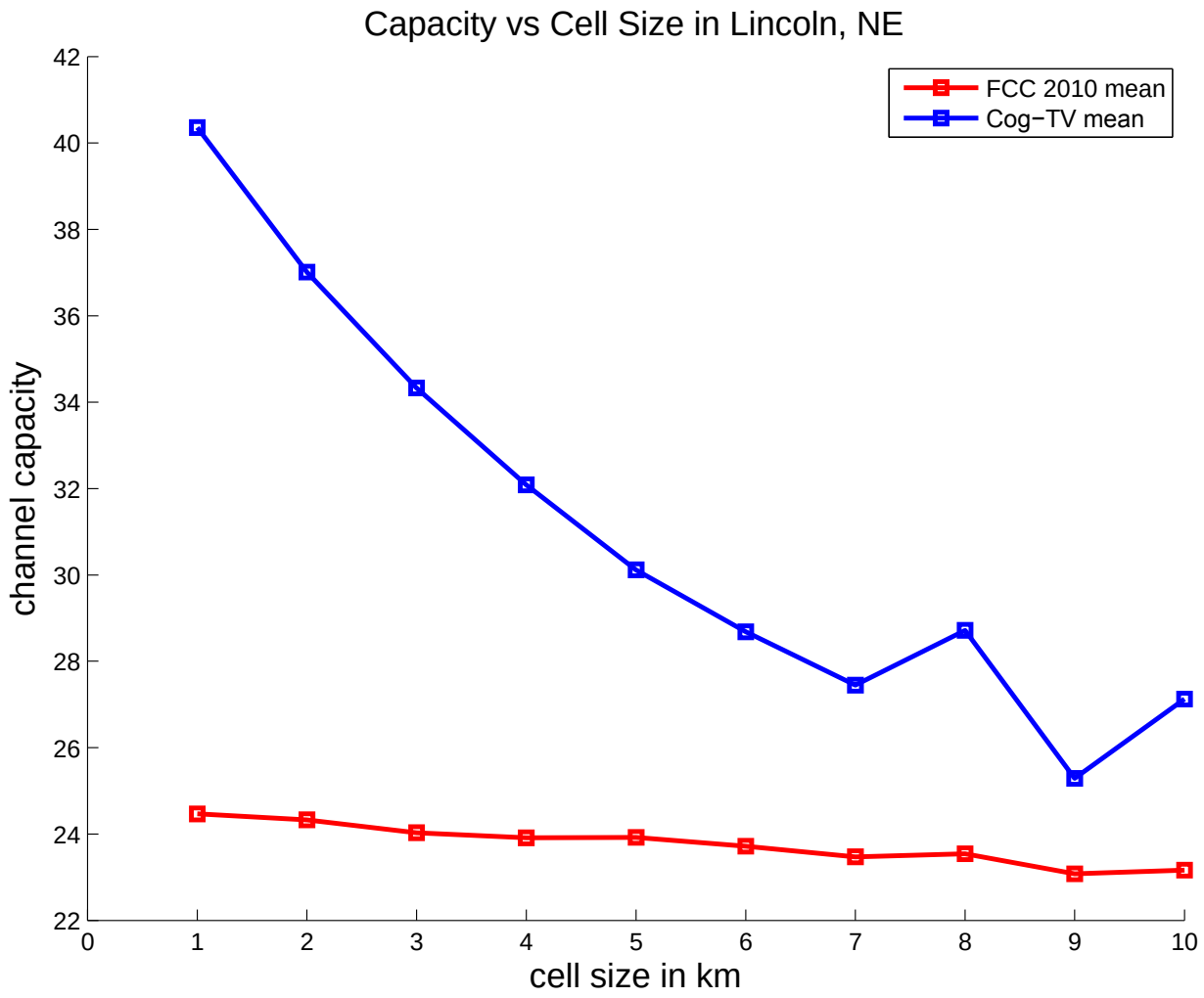


7 km

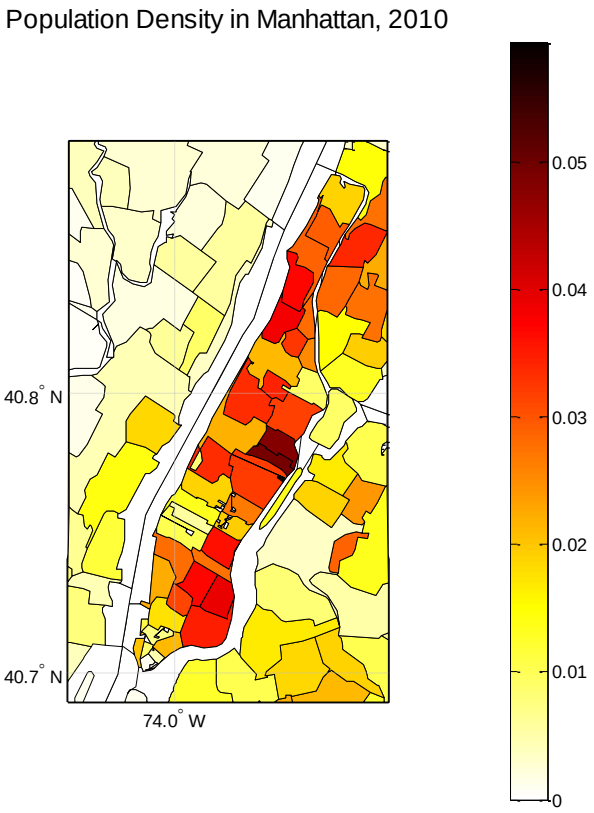


10 km

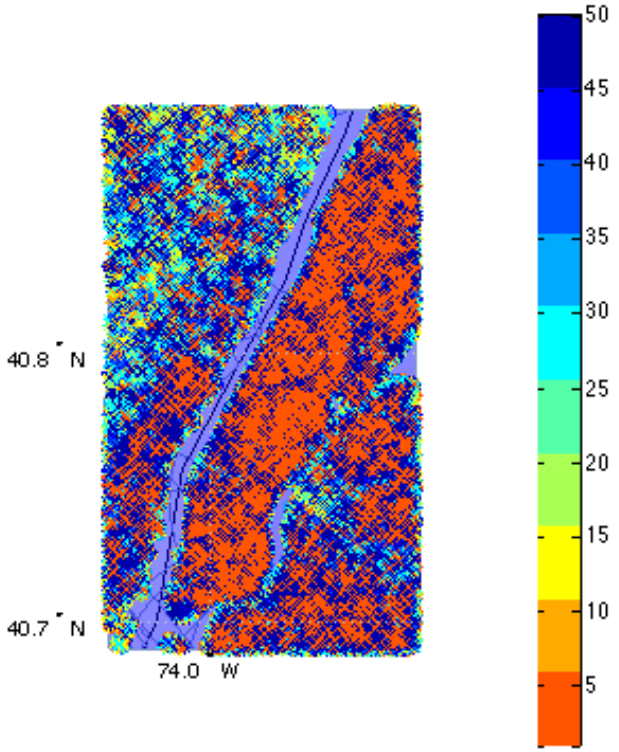
Capacity vs Cell size Lincoln, NE



Manhattan, New York

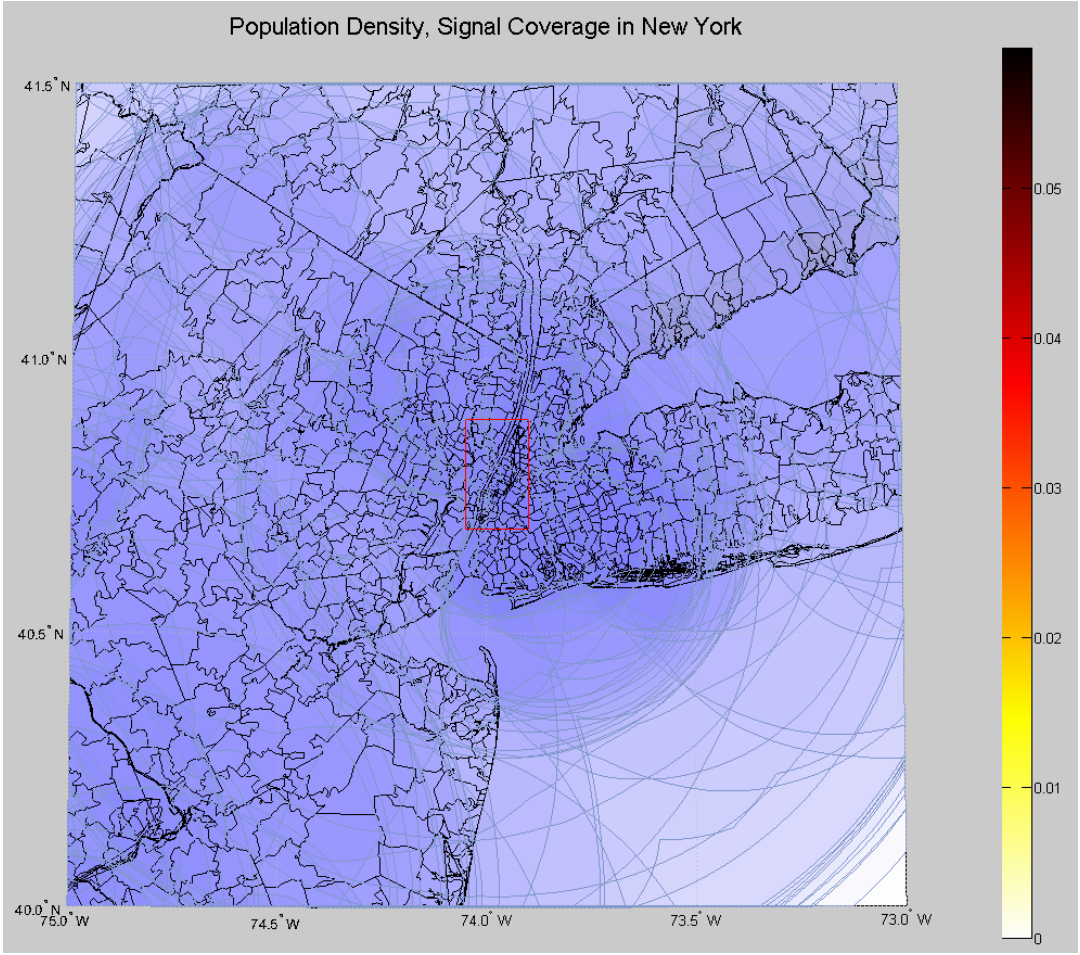


Population Density

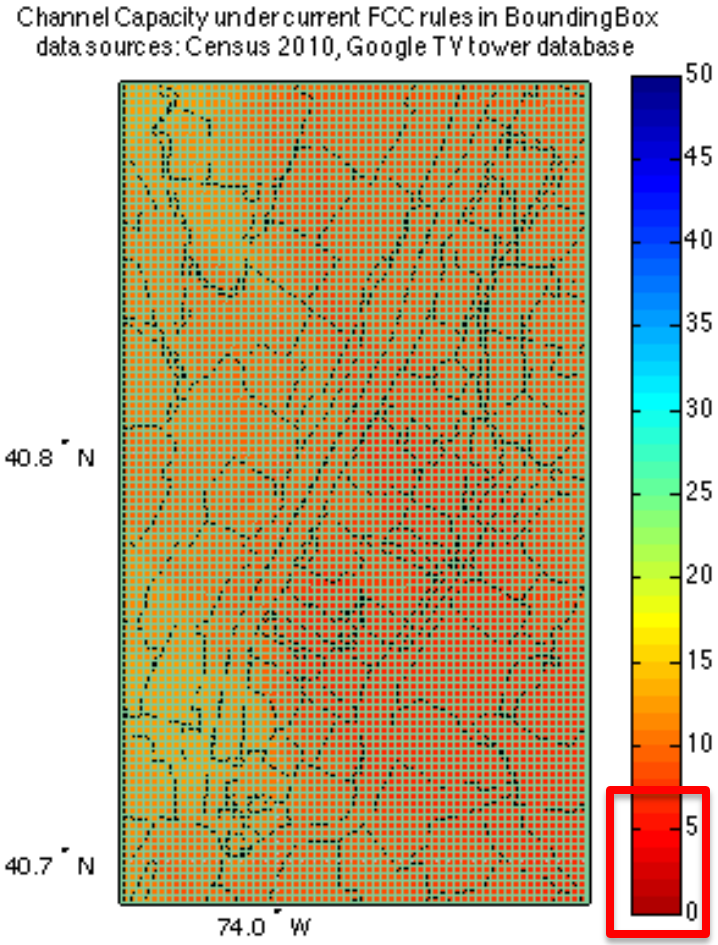


Channel selection

Population, TV Signal Coverage, NY



Manhattan, NY, 0.2km cell



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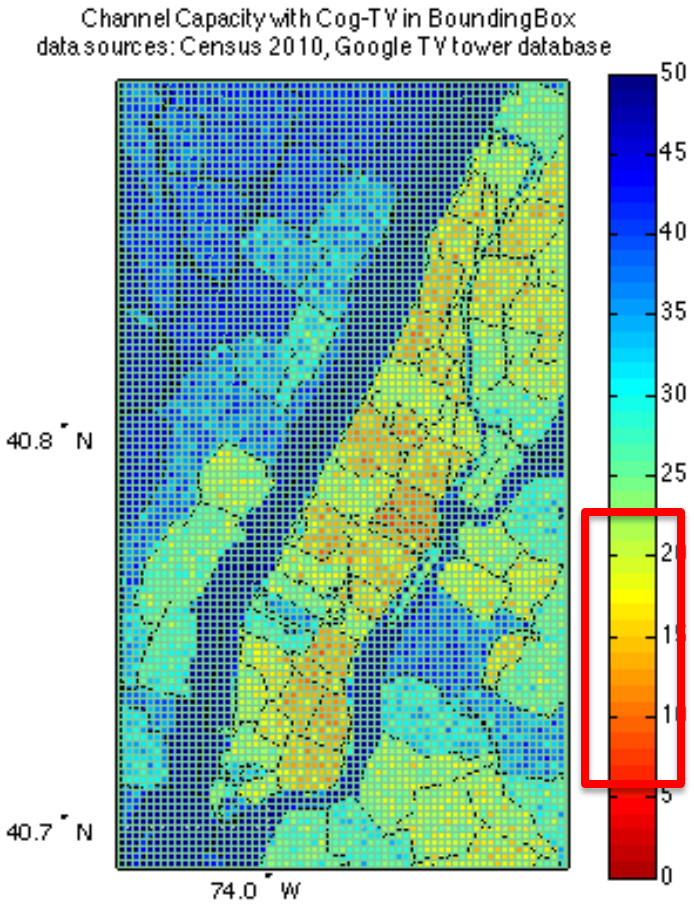

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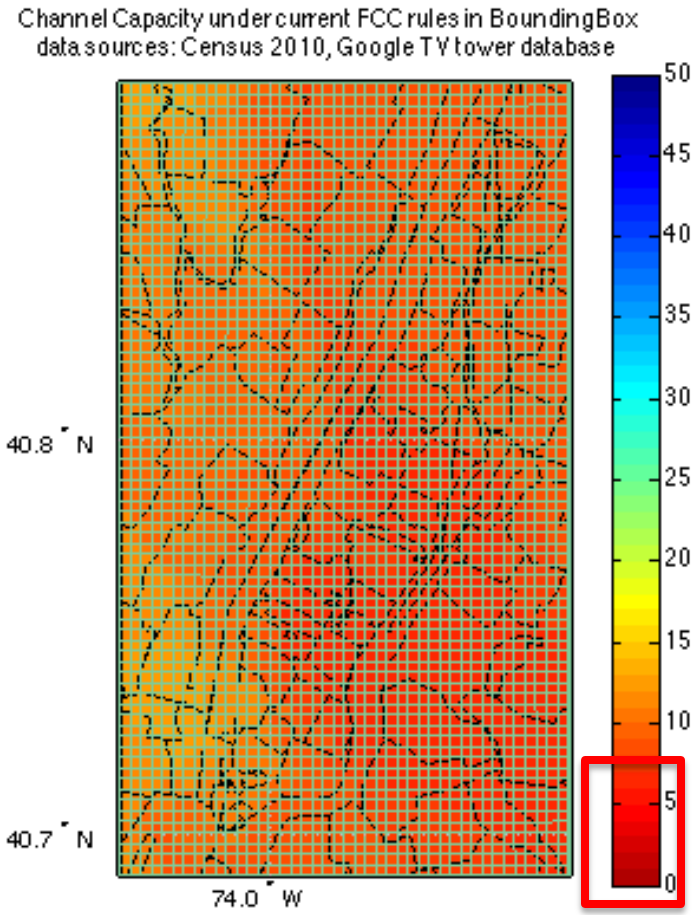
Manhattan, NY, 0.3km cell



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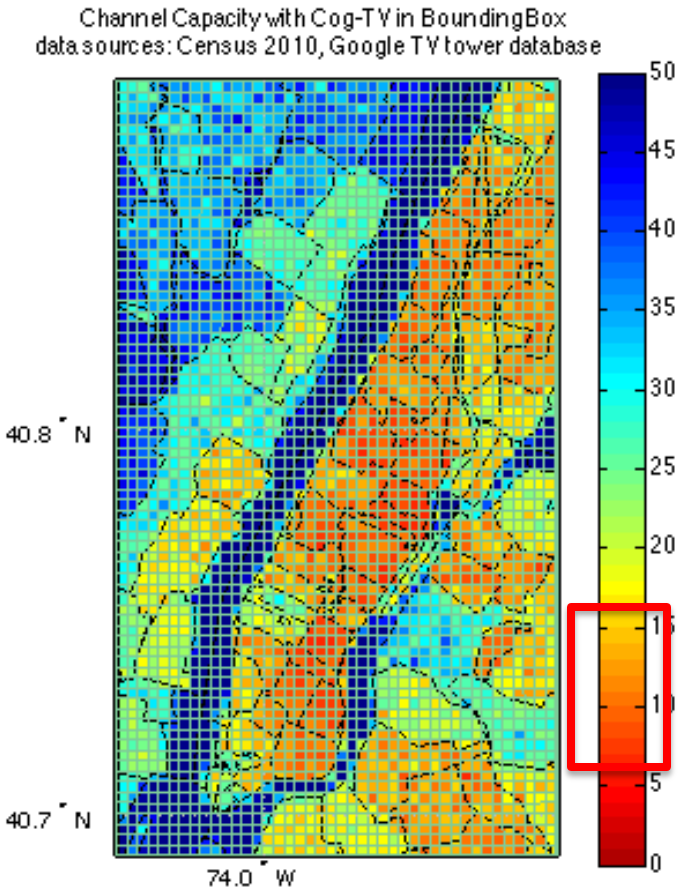
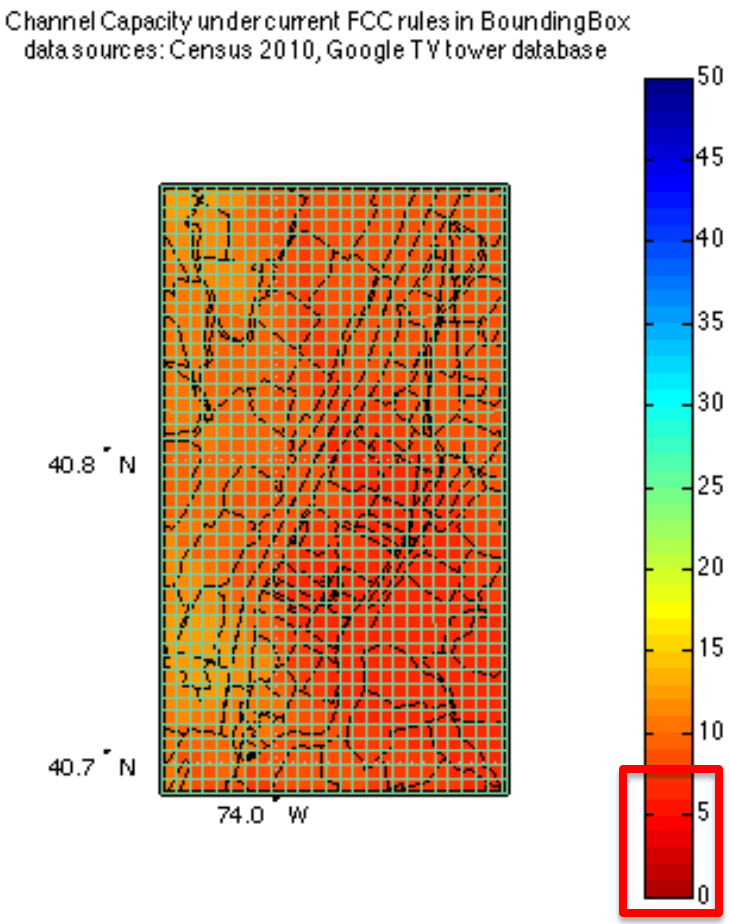
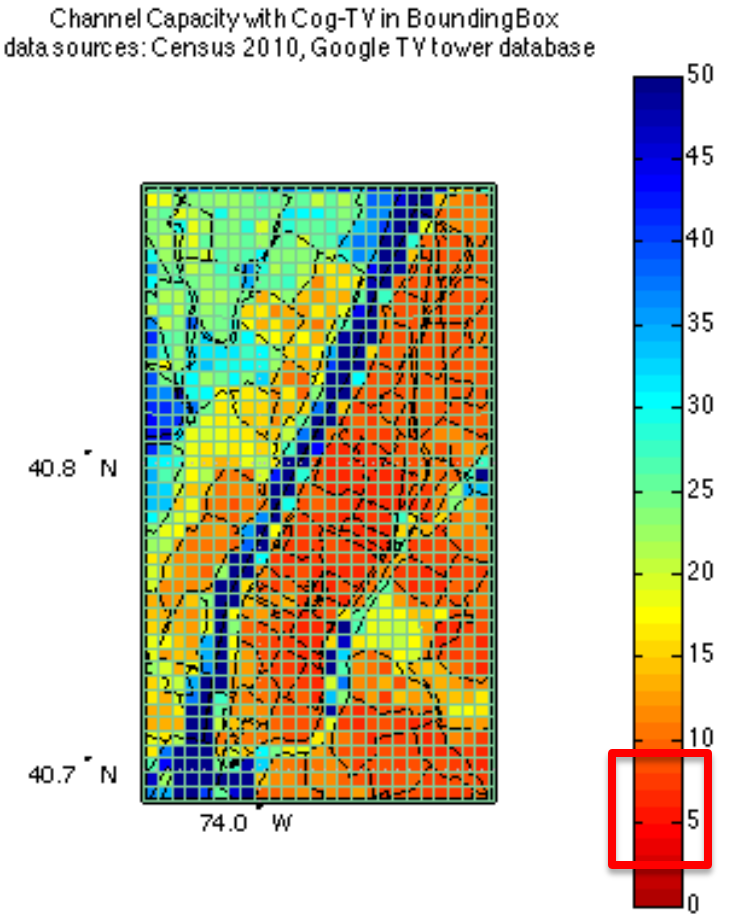


Cog-TV

Manhattan, NY, 0.5km cell

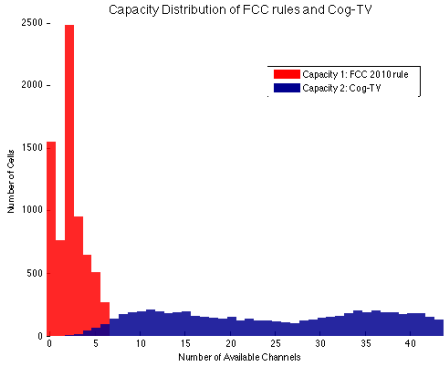


FCC

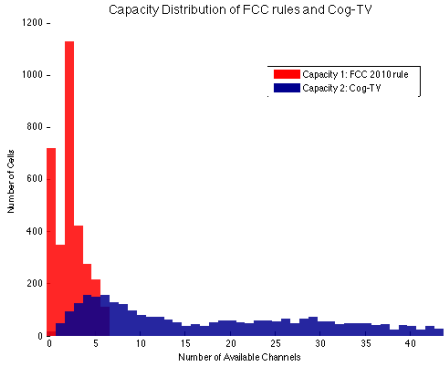


Cog-TV

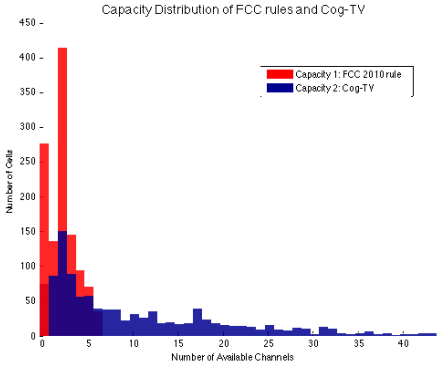
Available Channels in Manhattan, NY (FCC vs Cog-TV)



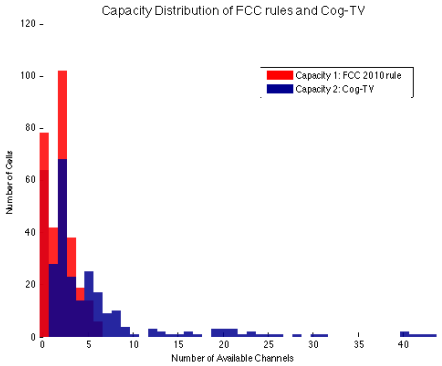
Cell Size: 200 m



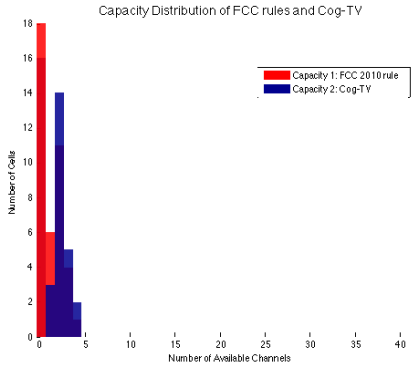
300 m



500 m

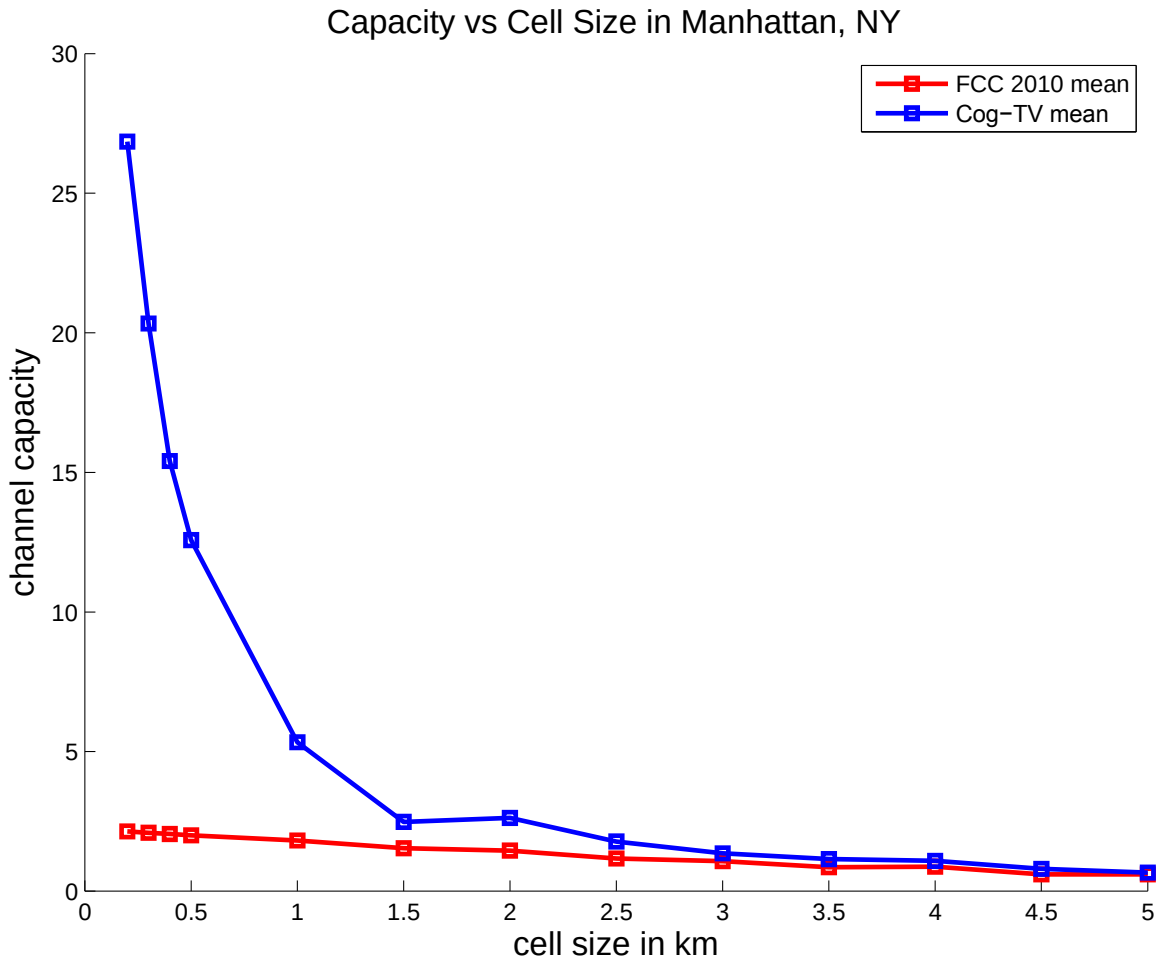


1 km



3 km

Capacity vs Cell size Manhattan, NY



CORN^2:

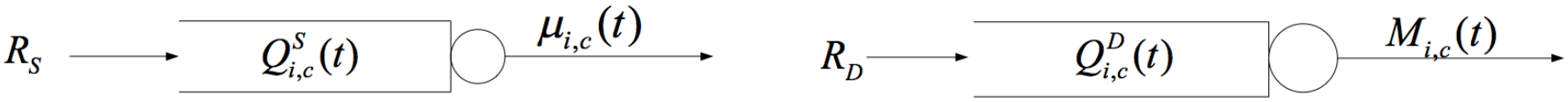
Correlation-Based Cooperative Spectrum Sensing in CRNs

[D. Xue, E. Ekici, M. C. Vuran, ``(CORN)^2: Correlation-based Cooperative Spectrum Sensing in Cognitive Radio Networks,'' *in Proc.* ***Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt'12)***, Paderborn, Germany, May 2012.

- Local information essential to assess spectral availability
- Most observations are highly correlated in
  - Space
  - Time
  - Spectrum
- **Objective:**
  Leverage correlations for cooperative spectrum sensing to minimize energy consumption
  Develop (centralized and distributed) sensing scheduling algorithms
- Nodes that perform local sensing broadcast their results
- Past and current sensing results as well as results obtained from nearby nodes are combined
- A long-term target sensing information quality is maintained

CORN²:

Correlation-Based Cooperative Spectrum Sensing in CRNs

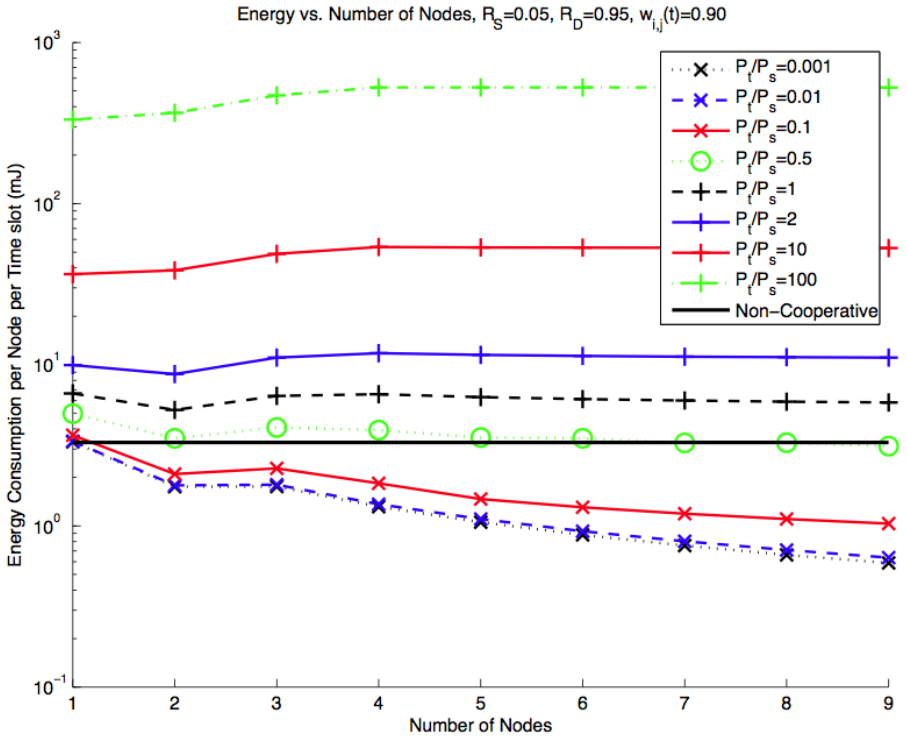


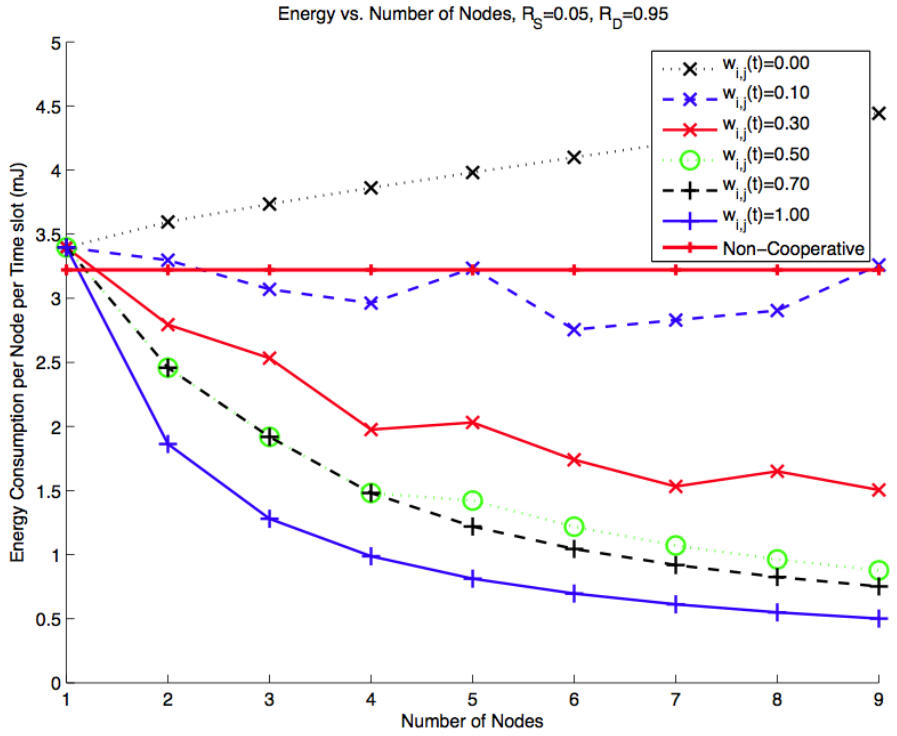
(a) Local Sensing Queue $Q^S_{i,c}(t)$ (b) Total Sensing Deficiency Queue $Q^D_{i,c}(t)$

- Algorithm design involves two virtual queues:
  - *Local Sensing Queue* ensures that nodes perform sensing at a rate > R_S and do not cheat
  - *Sensing Deficiency Queue* ensures a sensing quality > R_D by eliminating deficiency at rate $M_{ic}(t)$
  - $M_{ic}(t)$ is the accumulation of all local sensing and information obtained from nearby nodes
  - The centralized solution ensures stability of all queues while minimizing total energy consumption
- Distributed Algorithm:
  - If total contribution of all neighbors is bounded, then a fully distributed algorithm exists
  - Bounded contribution holds for low SNR cases and when temporal correlation is high
  - The resulting algorithm is a solution to a MWM problem on a bipartite graph with local weights and constraints
    ➔ Can be computed locally

CORN²:

Correlation-Based Cooperative Spectrum Sensing in CRNs





$R_S = 0.05$, $R_D = 0.95$, $P_S = 3.5\text{mJ}$, $P_{Tx} = 0.1125\text{mJ}$, $w_{i,j}(t) = 0.90$